IRON ORE COMPANY OF CANADA

BENTONITE SUBSTITUTION PROGRAM

PHASE I: POT-GRATE TESTWORK WITH A SELECTED ORGANIC BINDER

FINAL REPORT

BY

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ACKNOWLEDGEMENT

On behalf of the Iron Ore Company of Canada, I would like to take this opportunity to express our sincere appreciation and thanks to the Department of Supply and Services Canada and CanMet, especially personnel designated to this project for the excellent assistance and collaboration during the very important phase of our Bentonite Substitution Program.

T.I. Martinovic, P.Eng.

EXECUTIVE SUMMARY

During the period of December, 1990 to March, 1991, the Iron Ore Company of Canada carried out Phase I of the Bentonite Substitution Program with a selected organic binder - Peridur 230.

This phase of the program was sponsored by the Department of Supply and Services Canada as a part of Canada/Newfoundland MDA Program and the Iron Ore Company of Canada.

The laboratory testwork showed that Peridur with a small addition of bentonite can be used to successfully control the balling process. The influence of a small amount of bentonite is especially helpful at higher filtercake moistures. The very low addition rates of Peridur as a binder require intensive premixing to be effective.

The pot-grate testwork results showed that pellet reducibility can be improved by 25% for acid pellet production and most other pellet quality variables can be maintained. Pellet silica is reduced by 0.5% which provides an additional benefit to the customer. Pellet swelling still remains as a problem for acid pellets. The use of other additives (dolomite, limestone or bauxite) are being explored to help control this swelling problem.

Furthermore, the testwork showed that an acceptable fluxed pellet quality in all aspects can be produced with Peridur.

The results are sufficiently encouraging to proceed with phase 2 of the program which will include additional pot-grate testwork and a commercial trial on one balling module at the Carol Pellet Plant. Basket firing tests of Peridur based pellets would be a part of the plant module trial and would provide additional information on pellet quality along with the assessment of Peridur as a replacement binder in the balling process.

Upon completion of this additional pot-grate testwork and plant scale test on one module, a detailed technical and economic assessment will be required to fully evaluate the viability of Peridur as a potential binder for pelletizing of Carol concentrate.

If the technical and economic aspects are favourable, phase 3 of our Bentonite Substitution Program will be a full scale commercial trial.

Programme de substitution de la Bentonite à la Compagnie minière IOC
Résumé exécutif

Au cours de la période de décembre 1990 à mars 1991, la Compagnie minière IOC a réalisé la phase I de son Programme de substitution de Bentonite par un agent liant organique: le Peridur 230.

Cette phase du programme a été financé par le Ministère des approvisionnements et services du Canada, le Programme d'aide au développement minéral de la province de Terre-Neuve et la Compagnie minière IOC.

Les essais en laboratoire ont démontré que le Peridur combiné à une petite quantité de Bentonite peut être utilisé pour contrôler avec succès le procédé d'agglomération des boulettes. L'apport d'une petite quantité de Bentonite est particulièrement utile dans le cas des mélanges agglutinés à forte humidité. L'ajout très graduel de Peridur comme agent liant nécessite cependant un mixage préalable complet pour être efficace.

Les résultats de nos essais dans des fours à creuset ont démontré que la réductibilité des boulettes acides peut être améliorée de 25% tout en maintenant toutes les autres propriétés intactes. Le taux de silice se trouve à être réduit de 0,5% ce qui représente un avantage supplémentaire pour le client. Le gonflement demeure un problème dans le cas des boulettes acides. L'emploi d'autres additifs (Dolomie, Pierre à chaux ou Bauxite) sont à l'étude pour trouver une solution à ce problème.

De plus, les essais ont démontré qu'une qualité acceptable de boulette auto-fondante peut être produite avec le Peridur.

Les résultats sont donc suffisamment encourageants pour passer à la phase II du programme qui comprendra d'autres essais en four à creuset et un essai à l'échelle commerciale sur un module de bouletage à l'usine. Les tests de cuisson avec Peridur feraient partie de l'essai commercial et nous permettraient d'obtenir des données supplémentaires sur la qualité des boulettes obtenues et sur l'efficacité du Peridur comme agent liant alternatif.

Après complétion de ces expériences dans les fours à creuset et sur un module de production à l'usine, un rapport technique et économique détaillé sera nécessaire pour évaluer précisément la viabilité du Peridur comme agent liant pour l'agglomération des boulettes à base de concentré de Labrador City.

Si les résultats économiques et techniques sont concluants, la phase III de notre Programme de substitution de la Bentonite comprendra un essai complet à l'échelle commerciale.

1. INTRODUCTION AND OBJECTIVES:

The use of bentonite as a pelletizing binder has been a standard practice in the iron ore industry since the beginning of pellet production.

In 1988, the Iron Ore Company of Canada carried out the second stage of a program on the development of an acceptable substitute-organic binder in place of bentonite for the pelletizing of Carol concentrate. This phase of the program was sponsored by MDA - 1 program. The program covered an evaluation of various potential organic binders on laboratory and pot-grate (Pilot Plant) scale.

The test results with organic binders were compared with bentonite based pellets. It was found that for acid pellet production, some flux addition (dolomite or limestone) would be necessary in order to meet all of the physical and metallurgical properties of fired pellets.

Peridur was found to be the most promising potential organic binder. It was recommended that further pot-grate testwork be carried out with an optimised Peridur formula for Carol concentrate. The primary objective of this testwork was to resolve swelling problem for acid pellet production. The pot-grate testwork would include the optimization of the Peridur addition rate, firing cycle, minor flux addition if necessary, etc. This testwork would provide the necessary technical parameters for a potential commercial trial on one pelletizing line at the Carol Pellet Plant. With respect to fluxed pellet production with use of Peridur as a binder the testwork showed that an acceptable pellet quality can be produced including the swelling property. Further pot-grate testwork was recommended for acid pellets with Peridur as a binder in order to resolve swelling problems.

The purpose of the Bentonite Substitution Program is to find a suitable potential substitute binder for bentonite for pelletizing of Carol concentrate. In the past an acceptable pellet quality had been produced by using bentonite as a binder. However, its' quality, availability and rising cost have become important in considering today's stringent pellet quality requirements. Due to the lack of suitable quality of bentonite deposits in Canada, the material has to be imported from the United States and Overseas. Taking this into consideration and the adverse effect of bentonite addition to the pelletizing mix, increased impurities in the pellets (product) due to the bentonite's chemical composition, bentonite replacement is becoming an increasing priority.

Bentonite increases gangue content in pellets, adds about 0.5% silica. Conversely this increase in silica results in loss of iron units, which must be compensated for by increasing the concentrate grade, which decreases overall iron recovery and impacts on production cost. In addition because more stringent pellet quality demands lower silica and less impurities, bentonite is becoming a far less desirable pelletizing binder.

The objectives of the proposed project (Phase I) are as follows:

- To evaluate the improved formula of Peridur 230, an organic binder, as a potential substitute binder for bentonite for pelletizing of Carol concentrate.
- To carry out detailed laboratory and pot-grate testwork with the selected organic binder, Peridur 230, to investigate if an acceptable pellet quality can be produced with the use of this potential organic binder for acid pellet production.
- Establish operating parameters for balling and induration to be used for the plant scale test on one pelletizing line at the Carol Pellet Plant, providing all of the pellet quality parameters are met, based on full scale pot-grate test results.

2. PROJECT SCOPE:

Bentonite Substitution Program - Phase I: Pot-grate testwork with a selected organic binder included detailed laboratory and pot-grate testwork in order to establish the operating parameters for the plant trial.

The scope of the project focused mainly on acid pellets and included the following:

1. Tire balling with a selected organic binder, Peridur, to establish the guidelines for pot-grate disc balling such as addition rates, ballability, etc.
2. Full scale pot-grate testwork which consists of 1m disc balling and pellet firing in a pot-grate machine which is a pilot scale prototype pelletizing machine. This part of the testwork covered the following:
   - Baseline tests with bentonite addition which was used for comparison with Peridur produced pellets.

- Greenball production with Peridur addition and pellet firing in a pot-grate machine.

- Greenball production with small quantities of bentonite and Peridur which is a partial bentonite substitution for acid pellet feed.

- Greenball production and pellet firing with some other additives in addition to binders (dolomite, limestone or bauxite) in order to meet all of the pellet quality parameters including swelling.

- Optimization of balling and firing in order to establish operating parameters such as Peridur addition, additives, ballability, firing cycle, grate factors, etc. Also optimization of chemistry, physical and metallurgical properties of pellets with Peridur as a binder was part of the pot-grate testwork.

Tire balling and full scale pot-grate testwork have been carried out at the Centre de Recherches Minerales, Quebec City. Therefore, the details of the testwork, test results, conclusions and recommendations can be obtained from attached CRM's report.

The work on this project was carried out under the auspices of the Canada Center for Mineral and Energy Technology, Energy, Mines and Resources, Canada. The designated CanMet Scientific Authority was John Wilson, who continuously monitored the progress of the program and closely worked with the Iron Ore Company of Canada's designated project leader, Tom Martinovic.

CONCLUSIONS AND RECOMMENDATIONS

Laboratory and pot-grate testwork with the selected organic binder, Peridur 230, as a potential binder for pelletizing of Carol concentrate revealed the following:

1. With complete bentonite substitution, the optimum addition rate of the selected organic binder, Peridur 230, appears to be at 0.07%.

2. With respect to greenball production with the use of Peridur, a small quantity of bentonite (0.1 to 0.2%) is beneficial to control sensitivity to greenball moisture variations. Also, due to the small quantities of Peridur added, the mixing of the binder with concentrate is sensitive. Premixing of Peridur with other additives such as limestone, dolomite, etc. improves the binder performance.

   The addition of an additive called "Peridur DS" to Peridur 230 showed similar results with the exception of better control of greenball moisture due to its higher absorption capacity.

3. Use of Peridur for acid pellets as a binder and its effect on fired pellet quality can be summarized as follows:

   - Tumble index (+6.3mm) with the use of Peridur as a binder is 0.5 to 1.0% lower compared to the bentonite based pellets.

   - Fired pellet compressions are comparable to those of bentonite pellets.

   - The reducibility of fired pellets with Peridur is about 25% higher than bentonite based pellets. This is one of the major benefits achieved with Peridur as a binder. Pellet silica is reduced by about 0.5%, which would provide an additional benefit to us and our customers.

   - The swelling property of pellets is considerably higher with Peridur and above an acceptable range. It should be noted that the swelling problem with the use of Peridur is still not completely resolved for acid pellets. However, considerable progress has been made during the course of this program.

   - The low temperature disintegration, LTD property of pellets was not affected with the use of Peridur.

- High temperature softening of Peridur pellets is in the same range as for bentonite pellets.

- Degradation degree of Peridur pellets for Hearth Layer recycling was similar to bentonite pellets.

- Acid Peridur pellets may require slightly higher firing temperatures.

4. The small addition of dolomite (0.75 to 1.5%) to acid pellets with Peridur as a binder resulted in some improvement in swelling property but not to an acceptable level. With dolomite addition physical properties were also slightly improved while the LTD property was adversely affected. Therefore, the use of dolomite addition requires careful consideration.

5. Use of 0.75 to 1.5% limestone addition to Peridur based acid pellets did result in greater overall pellet quality improvements. However, improvement in swelling was not enough to meet the customers specifications below 20% maximum swelling value.

6. Bauxite addition of 1% to acid pellets with Peridur as a binder improved swelling property to an acceptable level. However, the reducibility of pellets was drastically reduced and comparable to bentonite based pellets. Therefore one of the main expected benefits (increase reducibility) of Peridur was diminished with bauxite addition.

7. The testwork confirmed previous findings that an acceptable fluxed pellet quality in all aspects can be produced with the use of Peridur as a binder.

   The greenball and fired pellets quality for optimum pot-grate tests are shown in summary tables 1 and 2. For additional details, refer to CRM's report.

8. Considerable progress has been made during this phase of our Bentonite Substitution Program. The results are encouraging enough to proceed with phase 2 of the program, which will include additional pot-grate testwork and a commercial trial on one balling module at the Carol Pellet Plant. The basket firing tests of Peridur based pellets would also be part of the plant module trial. The test results of this phase would provide additional information on pellet quality along with the assessment of Peridur as a replacement binder in the balling process.

   Upon completion of this additional pot-grate testwork and plant scale test on one module, a detailed technical and

economic assessment will be required to fully evaluate the viability of Peridur as a replacement binder for bentonite.

Providing the technical and economic aspects are favourable, phase 3 of our Bentonite Substitution Program will be a full scale commercial trial at the Carol Pellet Plant.

TABLE #1: POT GRATE TESTWORK – GREENBALL PROPERTIES

TEST#	%BENT	%PER	%DOLO	%BAUX	%LIMES	%H2O	DROPS	WET kg	DRY kg
1	0.8	-	-	-	-	8.7	11	1.3	6.6
2	-	0.07	-	-	-	9.1	17	1.6	4.9
3	-	0.07	-	-	-	8.9	19	1.3	5.1
4	-	0.09	-	-	-	8.9	19	1.4	5.7
5	0.2	0.07	-	-	-	9.0	16	1.3	6.2
6	0.4	0.04	-	-	-	9.5	19	1.4	4.1
7	-	0.07	0.75	-	-	8.9	17	1.5	4.7
8	-	0.07	1.50	-	-	9.0	19	1.6	4.4
9	-	0.07	-	-	0.75	8.9	20	1.4	4.6
10	-	0.07	-	-	1.50	8.9	20	1.6	4.7
11	-	0.07	-	-	-	9.3	17	1.4	3.8
12	-	0.07	-	1.0	-	9.2	20	1.6	4.6
13	0.2	0.05	-	-	-	9.3	16	1.2	3.4
14	-	0.07	7.5	-	3.0	9.2	19	1.6	4.3
15	0.80	-	7.5	-	3.5	9.2	18	1.4	5.1
16	-	0.07	-	0.50	-	8.9	19	1.6	4.6
17	-	0.05	-	-	1.00	8.8	15	1.4	3.5

TABLE # 2: POT GRATE TESTWORK
FIRED PELLET PROPERTIES

TEST #	BINDER ADDITION		FLUX ADDITION		PHYSICAL PROPERTIES				METALLURGICAL PROPERTIES				
					TUMBLE		COMPRESSION						
	% BENT	% PER	% DOL	% LIM	+6.3	−0.5	AVG.	STD	POR %	SWEL %	RED R40	LTD +6.3	LTD −0.5
1B	0.8	–	–	–	96.3	3.5	272	55	26.4	20.6	0.54	94.0	5.0
2B	–	0.07	–	–	95.4	4.5	270	41	27.8	33.2	0.75	94.5	5.1
3A	–	0.07	–	–	96.1	3.8	271	42	28.0	28.3	0.74	94.6	5.2
4A	–	0.09	–	–	95.9	4.1	253	51	28.3	31.0	0.75	95.6	4.3
5B	0.2	0.07	–	–	95.8	4.1	251	45	27.9	28.7	0.71	95.1	4.8
6A	0.4	0.04	–	–	95.5	4.4	256	53	27.7	26.0	0.69	93.8	5.7
7A	–	0.07	0.75	–	96.2	3.8	284	42	28.2	27.5	0.76	93.4	5.6
8A	–	0.07	1.50	–	95.7	4.1	269	42	28.5	24.7	0.72	93.3	6.5
9B	–	0.07	–	0.75	96.1	3.8	291	60	28.0	29.5	0.68	95.3	4.5
10A	–	0.07	–	1.50	95.7	4.2	275	55	28.0	24.6	0.71	96.8	3.1

TABLE # 2: POT GRATE TESTWORK
FIRED PELLET PROPERTIES

TEST #	BINDER ADDITION		FLUX ADDITION			PHYSICAL PROPERTIES				METALLURGICAL PROPERTIES				
	% BENT	% PER	% DOL	% LIM	% Baux	TUMBLE +6.3	TUMBLE −0.5	COMPRESSION AVG.	COMPRESSION STD	POR %	SWEL %	RED R40	LTD +6.3	LTD −0.5
11B	0.07	NEA	–	–		95.4	4.5	277	57	27.5	28.1	0.82	94.4	5.4
12A		0.07	–	–	1.0	95.6	4.3	276	62	27.5	19.8	0.54	94.3	5.1
13C	0.2	0.05				95.9	4.0	287	54	26.9	26.8	0.72	95.0	4.7
14C		0.07	7	3		96.3	3.6	266	71	28.0	9.7	1.12	96.3	3.4
15B	0.8	–	7	3		96.3	3.3	266	67	26.0	10.0	0.92	93.1	5.3
16B		0.07			1.0	96.0	3.8	302	71	26.5	19.6	0.52	95.3	4.0
17B		0.05		1.0		95.7	4.2	307	78	27.3	26.9	0.74	96.4	3.2

PRODUCT SHEET
ACID PELLET CARGOS - I.O.C.C.
4.75% SiO2

SPEC 90-06

[redacted]	[redacted] AT-GSPT-LES	[redacted] MIN	[redacted] MAX
Chemistry			
Major Elements			
% Iron, Fe	65.73	65.23	65.97
% Ferrous Iron, Fe^{++}	0.27	0.09	0.68
% Silica, SiO2	4.75	4.55	4.96
Trace Elements			
% Phosphorus, P	0.008	0.007	0.008
% Manganese, Mn	0.10	0.06	0.18
% Alumina, Al2O3	0.28	0.21	0.33
% Calcium, CaO	0.46	0.34	0.47
% Magnesium, MgO	0.33	0.18	0.54
% Titanium, TiO2	0.030	0.025	0.036
% Potassium, K2O	0.012	0.009	0.027
% Sodium, Na2O	0.020	0.016	0.031
% Sulphur, S	0.002	0.001	0.014
% Vanadium, V	< 0.010		
% Loss On Ignition, LOI	0.05 *	0.00	0.12
% Carbon, C	0.010		
% Zinc, Zn	0.001		
% Arsenic, As	< 0.010		
% Lead, Pb	< 0.002		
% Combined Water, H2O	0.030		
% Nickel, Ni	< 0.003		
% Chromium, Cr	0.014		
% Copper, Cu	0.001		
Moisture	Variable, depending on customer		
PHYSICAL			
Size Structure			
+ 19.0mm (+3/4") ISO 4701	0.1	0.0	0.4
+ 12.5mm (+1/2") ISO 4701	11.5	7.6	16.5
- 12.5mm + 9.5mm (+3/8") ISO 4701	75.0	71.0	78.5
- 9.5mm + 6.3mm (+1/4") ISO 4701	11.5	8.0	16.0
- 6.3mm (-1/4") ISO 4701	1.9	0.9	2.5
Tumble Index (+6.3mm) ASTM E279-89	96.4	94.6	98.1
Q Index	93.7	92.4	94.5
Compression avg %(kg) ISO 4700	230	208	268
Compression 2s %(kg) ISO 4700	121	91	148
Compression %-81kg ISO 4700	< 5.0	0	5
Reduction/Swelling			
% porosity ISO 4698	29.58	28.53	30.98
% swelling ISO 4698	17.7	13.8	21.0
LTD +6.3mm ISO 4698	90	83	94.5
LTD -0.5mm ISO 4698	5.14	3.2	7.7
R40 ISO 4698	0.62	0.53	0.71

DATE: 90-10-05
REVISION ____
APPROVED _____

* YEAR END COMPOSITE

PRODUCT SHEET
ACID PELLET CARGOS - I.O.C.C.
5.0% SiO2

SPEC 90-07

	EXPECTED ANALYSIS AT SEPT-LEB	RANGE MIN	RANGE MAX
Chemistry			
Major Elements			
% Iron, Fe	65.6	65.3	65.9
% Ferrous Iron, Fe++	0.22	0.18	0.27
% Silica, SiO2	5.0	4.8	5.2
Trace Elements			
% Phosphorus, P	0.008	0.008	0.008
% Manganese, Mn	0.11	0.09	0.13
% Alumina, Al2O3	0.27	0.24	0.31
% Calcium, CaO	0.47	0.40	0.66
% Magnesium, MgO	0.36	0.28	0.44
% Titanium, TiO2	0.032 *	0.030	0.035
% Potassium, K2O	0.014 *	0.014	0.015
% Sodium, Na2O	0.022 *	0.022	0.027
% Sulphur, S	0.002 *	0.001	0.003
% Vanadium, V	< 0.010		
% Loss On Ignition, LOI	0.13 *	0.12	0.13
% Carbon, C	0.010		
% Zinc, Zn	0.001		
% Arsenic, As	< 0.010		
% Lead, Pb	< 0.002		
% Combined Water, H2O	0.030		
% Nickel, Ni	< 0.003		
% Chromium, Cr	0.014		
% Copper, Cu	0.001		
Moisture	Variable, depending on customer		
PHYSICAL			
Size Structure			
+ 19.0mm (+3/4") ISO 4701	0.1	0.0	0.4
+ 12.5mm (+1/2") ISO 4701	13.6	10.0	16.0
- 12.5mm +9.5mm (+3/8") ISO 4701	75	72	77
- 9.5mm +6.3mm (+1/4") ISO 4701	10	8	11
- 6.3mm (-1/4") ISO 4701	1.3	1.0	2.5
Tumble Index (+6.3mm) ASTM E279-89	95.3	94.3	96.0
Q Index	93.8	92.0	94.8
Compression avg %(kg) ISO 4700	238	194	264
Compression 2s %(kg) ISO 4700	124	93	163
Compression %-91kg ISO 4700	1.0	0.0	4.1
Reconstitution			
% porosity ISO 4698	30.3	28.8	31.4
% swelling ISO 4698	17.0	13.7	22.7
LTD +6.3mm ISO 4696	90	85	95
LTD -0.5mm ISO 4696	5.1	2.7	7.4
R40 ISO 4695	0.64	0.58	0.70

DATE: 90-10-05
REVISION _____
APPROVED _____

* YEAR END COMPOSITE

PRODUCT SHEET
FLUX PELLET CARGOS - I.O.C.C.
4.75% SiO2

P.S. 90-04

	AT SHIPMENT	MIN	MAX
Chemistry			
Major Elements			
% Iron, Fe	62.0	61.6	62.3
% Ferrous Iron, Fe++	0.28	0.13	0.44
% Silica, SiO2	4.75	4.55	4.95
% Calcium, CaO	4.28	3.83	4.61
% Magnesium, MgO	1.6	1.6	2.0
% BAS (CaO/SiO2)	0.9	0.8	1.0
Trace Elements			
% Phosphorus, P	0.010	0.008	0.015
% Manganese, Mn	0.09	0.06	0.13
% Alumina, Al2O3	0.30	0.26	0.36
% Titanium, TiO2	0.040	0.019	0.340
% Potassium, K2O	0.018	0.014	0.026
% Sodium, Na2O	0.027	0.019	0.034
% Sulphur, S	0.016	0.010	0.024
% Vanadium, V	< 0.010		
% Loss On Ignition, LOI	0.290	0.270	0.310
% Carbon, C	0.050		
% Zinc, Zn	0.001		
% Arsenic, As	< 0.010		
% Lead, Pb	< 0.002		
% Combined Water, H2O	0.140		
% Nickel, Ni	< 0.003		
% Chromium, Cr	0.003		
% Copper, Cu	< 0.001		
% Moisture	Variable, depending on the customer		
PHYSICAL			
Size Structure			
+ 19.0mm (+3/4") ISO 4701	0.1	0.0	0.3
+ 12.5mm (+1/2") ISO 4701	7.7	5.6	9.1
- 12.5mm +9.5mm (+3/8") ISO 4701	75.0	72.9	80.0
- 9.5mm + 6.3mm (+1/4") ISO 4701	15.6	11.0	17.0
- 6.3mm (-1/4") ISO 4701	1.6	1.0	2.5
Tumble Index (+6.3mm) ASTM E279-90	96.0	95.5	96.5
Q Index	94.5	93.6	96.2
Compression avg %(kg) ISO 4700	204	192	229
Compression 2s %(kg) ISO 4700	110	104	119
Compression %-91kg ISO 4700	< 5.0	0.0	5.0
Pyrometallurgical			
% porosity ISO 4698	34.0	33.1	35.3
% swelling ISO 4698	16.4	12.3	21.0
LTD +6.3mm ISO 4696	87	82	90
LTD -0.5mm ISO 4696	8.0	5.9	11.4
R40 ISO 4696	1.20	1.16	1.30

DATE: 90-10-05

REVISION _____

APPROVED _____

PRODUCT SHEET
FLUX PELLET CARGOS - I.O.C.C.
5.0% SiO2

P.S. 90-05

[redacted]			
Chemistry			
Major Elements			
% Iron, Fe	61.55	60.95	62.04
% Ferrous Iron, Fe++	0.27 *	0.28	0.28
% Silica, SiO2	5.0	4.8	5.2
% Calcium, CaO	4.40	4.04	4.79
% Magnesium, MgO	1.90	1.70	2.16
% BAS (CaO/SiO2)	0.90	0.80	0.95
Trace Elements			
% Phosphorus, P	0.011 *	0.010	0.011
% Manganese, Mn	0.10 *	0.09	0.10
% Alumina, Al2O3	0.30 *	0.29	0.30
% Titanium, TiO2	0.024 *	0.022	0.026
% Potassium, K2O	0.018 *	0.017	0.018
% Sodium, Na2O	0.023 *	0.022	0.023
% Sulphur, S	0.01 *	0.01	0.02
% Vanadium, V	< 0.010		
% Loss On Ignition, LOI	0.34 *	0.33	0.35
% Carbon, C	0.050		
% Zinc, Zn	0.001		
% Arsenic, As	< 0.010		
% Lead, Pb	< 0.002		
% Combined Water, H2O	0.140		
% Nickel, Ni	< 0.003		
% Chromium, Cr	0.003		
% Copper, Cu	< 0.001		
% Moisture	Variable, depending on customer		
PHYSICAL			
Size Fraction			
+ 19.0mm (+3/4") ISO 4701	0.1	0.0	0.3
+ 12.5mm (+1/2") ISO 4701	7.7	5.6	9.1
- 12.5mm +9.5mm (+3/8") ISO 4701	75.0	72.9	80.0
- 9.5mm + 6.3mm (+1/4") ISO 4701	15.6	11.0	17.0
- 6.3mm (-1/4") ISO 4701	1.6	1.0	2.5
Tumble Index (+6.3mm) ASTM E279-89	98.0	96.5	98.8
CI Index	95.0	94.3	95.8
Compression avg %(kg) ISO 4700	204	193	223
Compression 2s %(kg) ISO 4700	110	83	130
Compression %-91kg ISO 4700	< 5.0	0.0	6.7
Pyrometallurgical			
% porosity ISO 4698	34.4	33.6	35.5
% swelling ISO 4698	16	12	20
LTD +6.3mm ISO 4696	85	75	91
LTD -0.5mm ISO 4696	9.0	5.5	13.5
R40 ISO 4695	1.20	1.15	1.35

DATE: 90-10-05
REVISION _____
APPROVED _____

* YEAR END COMPOSITE